DEVELOPMENT AND EVALUATION OF INDICES TO ASSESS THE ECOLOGICAL HEALTH OF THE PAHANG RIVER, MALAYSIA

By

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Abstract

Water is the essential need for life and all living things need water for living. Recently, the demand for clean and portable water has increased tremendously due to the rapid development and population growth. Since Malaysia has transformed from agriculture country to industrial based country, we are grappling with so many problems such as the increasing of waste, deterioration of water quality, and so on. Due to inadequate technical knowledge, we are not capable to handle and manage the increasing amount of waste. As a result, increasing amount of waste has polluted the water, degraded the habitat as well as caused a massive mortality of fish. Practically in Malaysia, assessment methods were focusing only on certain perspectives, e.g. chemical and physical parameters of water. The integrated assessment (combination between physical, chemical and biological component) to evaluate the health of aquatic environment is scarce. Furthermore, no specific and comprehensive assessment approach was established. For instance, water quality assessment is normally solely based on chemical and physical factors, while biological factor is neglected. This method only provides a partial perspective of water degradation. Moreover, it does not provide any information regarding biota status which becomes one of the main limitations of this method.

The main focus of present dissertation is the development of assessment method that could show more sensitivity towards the biological assemblage and at the same time it also could provide additional information to decision maker prior initiating any restoration works. Understanding the effects only from physicochemical parameters is not adequate to evaluate the condition of water environment because it involved the biota. At present, few studies were conducted in this river to evaluate the environment condition of this river, however, none of them focused on the developing of bio-assessment method to evaluate the biotic and abiotic condition in the river. Thus, the present study was designed to investigate the fish composition, assess the water and habitat quality, and integrate this information to develop comprehensive assessment method that is reliable, rapid manner and the results can be easily deliver and present to public. In addition, the development of this assessment is crucial for monitoring and managing our water environment where the threats of biodiversity are tremendously increased especially this river.

The Pahang River which is located in the Pahang state, Malaysia was selected as the study area. This river was chosen because it was regarded as the most valuable river in Malaysia that is rich in biodiversity, has great potential of water resources and remarkably contributes to economic growth. Twenty-one sampling sites were designed and monthly surveys were conducted from August 2007 until June 2010 to collect environmental variables as well as fish data. These data will were analyzed and used to evaluate the environmental health in this river. Prior to developing and integrating several indices to measure the ecosystem health, a comprehensive data on aquatic and environmental variables were needed. The fish surveys were conducted to collect biodiversity information on the fish fauna, while biotic variables were collected to monitor the concentration of these variables. From the survey results, not only fish composition are differs between river segments but also fish diversity and richness, where the downstream area were recorded the highest diversity as well as species richness. These results indicate that the diversity and species richness in this river was significantly influenced by river width, altitude, water quality and habitat quality. On the other hand, by using two-way indicator species analysis (TWINSPAN) and multidimensional scaling analysis based on fish occurrences, fish community assemblage pattern can be divided into four groups; (i) upstream A1, (ii) upstream A2, (iii) middle stream, and (iv) downstream stream groups. Further, these segments classification will be utilized to assign scoring criteria for the development of biological index.

Subsequently, the combination between water quality index (WQI) and habitat assessment were performed to evaluate the environmental conditions from abiotic point of view. The calculations of WQI are based on the procedure proposed by Department of Environment while designation of classes of beneficial uses was based on standard provided by the Interim National Water Quality Standards for Malaysia (INWQS). Six variables were considered as main variables; COD, BOD, TSS, NH_3N, pH and water temperature. Meanwhile for habitat assessment, a method that was developed by Barbour et al. (1999) was used. However, several attributes were modified to fit in with local conditions. Assessment results showed that human activities has deteriorated the water quality as well as degraded habitat quality of this river. As a result, it has significantly impact on fish composition in this river. After all, the combination of these two techniques could widen up our understanding on how aquatic life was affected by water and habitat quality.

The Pahang River which is located in the Pahang state, Malaysia was selected as the study area. This river was chosen because it was regarded as the most valuable river in Malaysia that is rich in biodiversity, has great potential of water resources and remarkably contributes to economic growth. Twenty-one sampling sites were designed and monthly surveys were conducted from August 2007 until June 2010 to collect environmental variables as well as fish data. These data will were analyzed and used to evaluate the environmental health in this river. Prior to developing and integrating several indices to measure the ecosystem health, a comprehensive data on aquatic and environmental variables were needed. The fish surveys were conducted to collect biodiversity information on the fish fauna, while biotic variables were collected to monitor the concentration of these variables. From the survey results, not only fish composition are differs between river segments but also fish diversity and richness, where the downstream area were recorded the highest diversity as well as species richness. These results indicate that the diversity and species richness in this river was significantly influenced by river width, altitude, water quality and habitat quality. On the other hand, by using two-way indicator species analysis (TWINSPAN) and multidimensional scaling analysis based on fish occurrences, fish community assemblage pattern can be divided into four groups; (i) upstream A1, (ii) upstream A2, (iii) middle stream, and (iv) downstream stream groups. Further, these segments classification will be utilized to assign scoring criteria for the development of biological index.

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After the determination of river classification and understanding the life history of each species, the development of fish characteristics list can be developed. This list considered as the most important data prior developing the IBI because it will be utilized as the main factors in IBI metrics selection. Regarding to the development and calculation of index of biotic integrity (IBI), fifteen metrics were integrated based on fish life history charcteristics such as species richness and composition, intolerant and tolerant species, trophic composition, spawning and habitat preference, and also fish health and abundance. The evaluation results based on the selected metrics seems corresponded well with fish composition, water quality and human impacts. Thus, it was suggested that the integration of selected metrics could be applied to evaluate the environmental conditions for this river because it could provide better evaluation and assessment result compared to single indicator when dealing with complex problems.

Even though species diversity in this river is high, commercially exploited edible species are rare due to the increasing of environmental degradation. In addition, the numbers of species that susceptible to biotic and abiotic have also continuously reduced. Thus, immediate solution to control and prevent these species from extinct are needed. One of the promising methods that can be used to monitor the probability of fish occurrences are by modelling. Many researchers have developed a model based on fish data and have suggested that the modelling could contribute in conserving targeted fish and environment condition in general. In this study, four fish species have been chosen to be model. The selection of fish species highly depends on their economic values and also was on the targeted list as protected species for Peninsular Malaysia proposed by Department of Fisheries. Statistical analysis known as generalized linear model (GLM) was conducted to model the occurrences of these species with regards to environmental variables. Then, to evaluate the accuracy of model results, area under the curve (AUC) was calculated. Based on the AUC values, all the models results were classified as acceptable and regard as useful application.

In summary, this study has demonstrated the environmental variables and human activities have influenced the fish composition assemblage. Based on four assessment methods that were used to evaluate the environmental condition of this river, bio-assessment based on fish data (IBI) provide better assessment results than other assessment methods. These assessment results could provide indispensible information in managing our water environment. Regarding to habitat assessment method and fish-based index, further refinement and improvement are needed to improve the evaluation accuracy. Instead of using GLM to predict the presence/absence of fish species, the development and application of modelling can be used to generate the hotspot based on fish fauna composition. Finally, some recommendations are given on how to improve the present works prior initiating any future research activities.

Chapter 1

Introduction

1.1 Background

Water is the essential need for life and all living things need water for living. Recently, the demand for clean and portable water has increased tremendously due to rapid development and population growth (DOE, 2006). Primarily, our drinking water resources are coming from river and reservoir and this situation will remain so for a long time to come (DOE, 2006). River water was regard as the main sources for drinking water, municipals water supplies, industrial, irrigation of agriculture lands, navigation, fishing and recreation. Malaysia was blessed with the immeasurable quantity of water which drained by more than 150 river systems. However, most of our streams and rivers are continuously suffering stresses from industrial and urban pollution, illegal industrial discharge, polluted storm water, littering and illegal dumping, which resulted in the degradation of the streams and rivers in both terms; water quality and water quantity (Zainuddin et al. 2010). Thus, preserving water quality and water quantity is one of the main priority in river improvement project to ensure we can cope with the increase in water demand in the future.

Since Malaysia has transformed from agricultural based country to industrial based country, we are grappling with so many problems such as the increasing of waste, deterioration of water quality, degradation of habitat and depletion of resources (Fig.1.1). Due to inadequate technical knowledge, we are not capable to handle and manage the increasing amount of waste. As a result, the increasing amount of waste has polluted the water, degraded the habitat as well as causing a massive fish mortality (DOE, 2006). In term of water environment quality, numbers of major rivers has turn into polluted river. According to a study conducted by the Department of Environment (DOE), the main causes of river pollution in Malaysia are domestic sewage, industries effluent discharge, agriculture fertilizer and urban diffuse sources (DOE, 2006). For example, the paper making industry has used chemical materials which are often required in its production. Normally, these chemical materials are poisonous to living things and required special treatment procedures to treat. Some producers just taking short cut by committing immoral actions by discharging their waste directly into the river. The river was used as an outlet to drain out the waste, in turn has deteriorate the water quality and harming the organism. Moreover, certain rivers also have become a tourist attraction and this has prompted the construction of hotels and resorts along the river bank. For instance, the upstream area of the Pahang River have to be in nature state, but, due to the deforestation, land clearing and land development, drastic change of the landscape features along this river was observed (Fig. 1.2). As a result, the surrounding soils have no roots to hold on to and soon will be eroded when the rains come; in turn the river becomes murky because of sudden increasing of suspended solids. As the water polluted, it will resulted in high cost of water treatment, declining in fisheries resources, and serious ecological degradation of aquatic environment (Bilotta & Brazier, 2008; Bash *et al.* 2001).

Fig. 1.1 (a) The rubbish trap in the downstream area, and (b) sand mining activities which could disturbed the bottom sediment that lead to the habitat degradation

(a)

(b)

Fig. 1.2 Current activities at upstream area of the Pahang River; (a) restaurant, resort and hotels was built on the floodplain area (b) fish cage for aquaculture

Having good water quality and physical environment is important for a healthy river and ecosystem system (Najah *et al.* 2009; Rin-Ping *et al.* 2009). The changes in water quality in the stream ecosystem were not only caused by the local pollution but also seasonal and geophysical regime factors (Ya-Yuan *et al.* 2010; Meador & Goldstein, 2003). Many studies have shown that water quality are very complex and have a lot of fluctuations which can be under the influence of hydro-chemical, hydro-biological and hydro-dynamical factors and processes (Lim *et al.* 2009; Karr *et al.* 1986; Juahir *et al.* 2010). In short, controlling chemical properties alone does not assure the ecological integrity of aquatic environments (Karr *et al.* 1986). To ensure the aquatic life can survive in changing environment, several basic conditions must be met. When the water conditions are not optimal, this situation will resulted in the increasing of stresses on living organism and could lead to species loss and die. For example, the extensive agriculture activities, excessive resource exploitation, intense industrial development, and declining of forestry area, could contribute in wide variety of stressors that could affect aquatic ecosystems.

According to the statistic published by Malaysia's National Biodiversity Policy (1998), there is greater diversity of flora and fauna in the country. Based on these data, there are about 300 species of will mammals, 700-750 species of birds, 350 species of reptiles, 165 species of amphibians and more than 300 species of freshwater fish. Freshwater habitats such as the lowland slow-flowing streams and upland rivers with water torrents support a diverse aquatic invertebrate fauna and variety of fish. Reduction of this biological diversity will distract the ecosystem balances as it is generally accepted that a certain amount of species and genetic diversity is needed to uphold the relations within the ecosystems and hence, maintain ecological services. Losing of this diversity means losing the ecosystem resilience, leading to adverse effects on human lives (Raja-Omar *et al.* 2004).

Regarding to river water pollution problems, it has a very long history. For instance, the rapid development of tin mining, traditional industries such as rubber and palm oil that started at the turn of the century about 100 years ago and have polluted the river. From the late 1960's Malaysia has pursued rapid industrialization supported by foreign investment. This condition has brought wealthiest and prosperity to the country. However, due to lack of enforcement and low awareness, the tremendous increases amount of industrial wastewater and other wastes are expected and these problems obviously were affected the environmental quality especially in the urban areas. Nowadays, as in many other developing countries, the state of rivers is appalling and in many urban areas, where the rivers have been literally turned into open sewers, some to the extent of being non-rehabilitate and we are paying it tolls (Chan *et al.* 2003)

A lot of researches have been conducted to identify the relationship between land use practices and water quality. A study by Weng & Mazlin, (2009) and Sulaiman *et al.* (2010) in major Malaysian rivers have suggested that the anthropogenic activities along the river have deteriorated the water quality, degraded potential habitat and decreased aquatic ecosystem as a whole. While a study by Gasim *et al.* (2009) at Chini Lake has mentioned that the changes of land use practice has increased the concentration of several parameters and have lead to decreases of biological assemblage. On the other hand, Ganasan and Hughes, (1998) and An *et al.* (2002) in their study have revealed that the fish composition could be an indicator to monitor the degradation of water environment. They have suggested that biological assemblage pattern can be used to monitor the changes in the aquatic ecosystem, because it reflects a combination of present and past ecosystem conditions

In Malaysia, river management and restoration works have always concentrating on beautifying and aesthetical improvement along the polluted river without taken into consideration on how to mitigate and/or reduce the amount of pollutant concentration. As a result, we never solved water quality problems. Usually, river rehabilitation works have focused on water quality improvement and landscape enhancement rather than providing essential habitat for aquatic life especially fish. With the splendid river landscape structure that was constructed using a concrete, it clearly do not provide and support preferable aquatic habitat the living things. With the increase of knowledge and technology in river rehabilitation works, there is an urgent need to restore back the natural hydrology and morphology of river and simultaneously recover the natural river ecology (Brookes & Shield, 1996). Therefore, to manage rivers effectively; it is a must to first measure the availability and condition of it resources. In earlier studies, the streams were only evaluated in terms of physico-chemical parameters. This approach has proved to be a best methodology to measure the quality of water. However, with the development of technologies and introduction of new knowledge, this method was suggested not efficiently produce a good results in assessing the aquatic life quality and stream health condition. Normally, stream health measurement have included the water quality, habitat quality, energy sources, hydrology and biota assessment (Karr *et al*. 1986). Thus, to ascertain the successful of river rehabilitation, all those condition must be fully fulfilled.

In Malaysia, until now there are no comprehensive assessment was established to evaluate the environment quality and water environment quality. Usually, the assessment methods were only focusing on certain perspectives, e.g. chemical and physical parameters of water. The integrated assessment (combination between physical, chemical and biological component) to evaluate the health of aquatic environment are scarce and there are no specific assessment approaches were established. For instance, water quality assessment is normally solely based on chemical and physical factors, while biological factor was neglected (Gasim *et al.* 2009; Ahmad & Shuhaimi-Othman, 2010; Ahmad *et al.* 2009). According to them, this method only provides a partial perspective of water degradation. Moreover, this assessment method does not provide any information regarding to biota status and this regards as one of the main limitation of this method. Therefore, new approaches are needed to assess the ecological health of water environment which suggested the integration of physical, chemical and biological indices.

The Pahang River ecosystem is said to be one of the most important ecosystem among other major rivers in Malaysia. It supports the local economic activities such as agriculture, aquaculture, fishery, eco-tourism, irrigation, and water supply for domestics and industries. However, rapid development such as urbanization and socio-economic activities has given a bad impact on the ecosystem (He *et al.* 2008: Tekolla, 2010). For example, land development and various sources of pollution exerted the fish population (Lee & Ismail, 1996). The Gombak River which is one of the major rivers in Malaysia has lost more than 50% of its original fish composition due to land development (Zakaria-Ismail, 1994).

The Pahang River has been noted as an important source of fish, the conservation biology of fish in this river is considerably limited. The work of Mohsin and Ambak (1983) has provided important information on the fishes and their distribution in the Peninsula Malaysia and a little information on the fishes in the upper catchment. While a study by Khan *et al.* (1996) was regarded as an extensive work aimed at conserving the fish biology in the Pahang River. In their study, Khan et al. (1996) has listed about 167 species of freshwater fish and about 130 species were found in the lower area. Later works by the Department of Fisheries (DOF) and the South East Asian Fisheries Development Centre (SEAFDEC) has only sampled 67 fish. Based on these findings, we can draw the conclusion that the numbers of fish species resources in this river are decrease. This result could serves as an important warning which shows that the ecosystem of this river is facing serious degradation.

Typically, the biological monitoring in Malaysia is merely to assess the diversity of fish species as well as to collect information on the fish species in a particular river. Only a few empirical studies are based on biological features using fish, macro invertebrates, or phytoplankton have been conducted to assess the relationship between biological assemblages with environment variables, to assess the ecological health of rivers in Malaysia. The study by Yap (1997) can be regards as the earliest study in Malaysia to classify Malaysian rivers by using biological indices, and this study has prompted rising research in this field (Ahmad *et al.* 2009; Suhaimi-Othman *et al.* 2010; Sohaili *et al.* 2005). In his study, Yap used phytoplankton communities in assessing the ecosystem health of the Bernam River. Regarding to the Pahang River, limited numbers of studies have been done to determine the relationship between biological assemblages with environmental variables. Furthermore, none of it has focused on the development of biotic integrity index.

By considering that there is no absolute river health assessment method has been established in Malaysia. The main purposes of this study are to evaluate the ecological health of river environment by focusing and developing a comprehensive assessment method for the Pahang River. Perhaps, by applying the basic theory and foundation of this method, I do hope that this method can be applied in other rivers in Malaysia in near future. To achieve these aims, several related statistical approaches will be applied, comprehensive discussion with related agency and basic foundation of studied area are really needed. Hopefully, this work could contribute in conserving and protecting our valuable resources.

1.2 Problem statement and research questions

As we know, river and human have a close relationship as the river serves as a means of transportation, sources of foods, water supply for domestic, industrial, and agriculture uses. With the increasing rate of urbanization, commercial activities and others activities, the quality of rivers began to experience impairment upon the occurrences of erosion, sedimentation and various kinds of pollution. This condition has prompt disharmony relationship and has had caused detrimental to these two parties. Although many environmental variables have been regards as the causative factors in degrading the water environment especially biota, these factors can be grouped into five major classes. Those major classes are habitat quality, biotic interactions, water quality, energy sources, and flow regime as shown in Figure 1.3. It was suggested that the alteration of one of these factors will resulted in major impacts on stream biota (Karr et al. 1986).

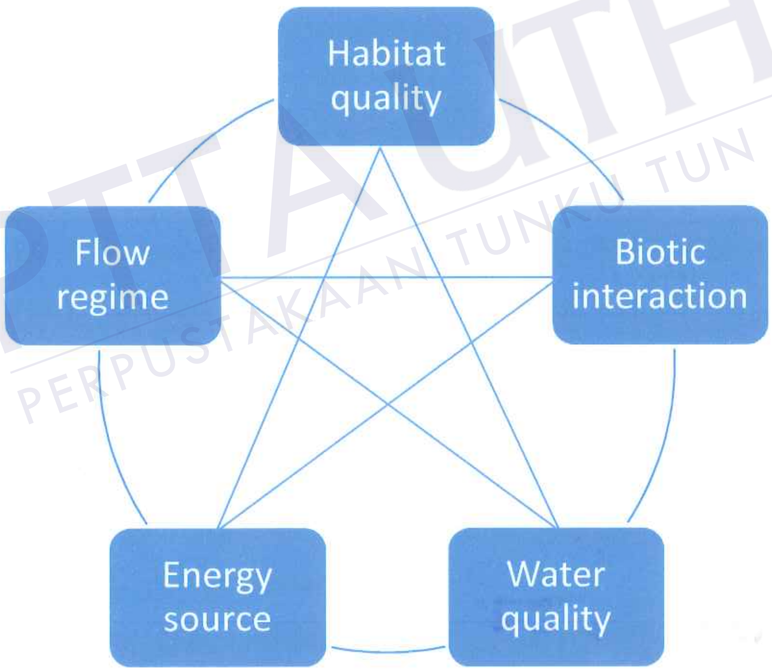

Fig. 1.3 Five major environmental factors that affect aquatic biota. The arrow indicate the relationships between every environmental components in the ecosystem, the changes of each component will effect on other factors (modified from Karr et al. 1986)

In order to measure and preserve the good environmental quality of this river from experiencing and suffering worse condition, several key questions were addressed and need to be answer through this study:-

1. Up to what extends the study area have been experiencing environmental and aquatic environment degradation problem?
    a. Explain about the current situation in Malaysian rivers and the Pahang River in specific
    b. General aquatic environment in Malaysian Rivers and the Pahang River in specific
2. Does the environmental degradation and water environment quality deterioration have negative effects on the fish composition and fish assemblage in this river?
    a. Explain about the fish species in this river
    b. Mention about the fish assemblage and composition pattern in this river with regards to environmental variables especially water quality and habitat quality.
3. How significant these problems have contributed to the fish assemblage/composition in this river?
    a. Explain the relationship by applying several statistical analyses (Generalized Linear Model (GLM), Canonical Correspondence Analysis (CCA), TWINSPAN, Principal Component Analysis (PCA), t-test, ANOVA and correlation test
4. How to estimate the ecological health of this river?
    a. F-IBI (Fish-Integrated biological Index)
    b. WQI (Water Quality Index)
    c. Habitat assessment
5. What are the necessary measurements needed to be taken into account to preserve good environmental quality along the river?
    a. How to control and improve the environmental condition along this river
6. Does river restoration is needed to improve the ecological health in this river?
    a. Proposed a mitigation work or suitable restoration works to improve the ecological health of this river
    b. Proposed conservation works to improve and increase the abundance of targeted fish species

1.3 Research objectives

By identifying and understand the problems in this river, the main objectives of this study were designed as follows:

i. To identify fish species in the river in terms of fish species composition and richness. To delineate the fish fauna based on species presence/absence and similarity by using two statistical approaches (two-way species indicator species (TWINSPAN) and multidimensional scaling analysis (MDS))

ii. To evaluate and describe the water quality and habitat quality of this river based on water quality index and habitat assessment,

iii. To develop and evaluate the ecological health of this river based on fish fauna as biological indicator,

iv. To model the occurrences of targeted fish species and determine the possible threat and then to propose conservation approach to conserve those selected fishes, and

v. To establish the relationship between fish species composition, water quality and habitat quality conditions.

1.4 Proposed approaches

In this study, the main objectives that needs to be achieved at the end of the study is to develop a practical ecological health assessment method based on fish composition that can be apply to evaluate the ecological health of this river. Moreover, the relationship between the fish richness with regards to environmental factors are established. Generally, water quality index (WQI) was used to classify the river and determine the status of water quality. The basic foundation of WQI is merely based on physicochemical parameters, and this approach is not strong enough to be utilized as a main tool to justify and evaluate the condition of aquatic condition. It was suggested that this index could not clearly describe the condition of the living things. Instead of relying on physicochemical parameters only to evaluate the river condition, it was suggested that the integration between physicochemical with bio-assessment could provide wider perspectives in describing the environment conditions. Therefore, this study was performed in order to develop the assessment method which includes the biological aspect as main parameters. Furthermore, the developed method must be easily apply to monitor the status of our river environment and the results must be easily understood by general users.

1.5 Description of the study area

The Pahang River is located in the state of Pahang on the Malaysia Peninsula (Fig. 1.4). The length of this river is estimated about 450 km. With this length, it was identified as the longest river in Malaysia Peninsula (Khan et al. 1996). For the purpose of fixing its length, the Tembeling River and the Pahang River is considered as one river (Takeuchi et al. 2007; Tekolla, 2010). The catchment area of this river is about 29,300 km^2. It consists of five sub-basin; the Pahang River Basin, the Bertam River basin, the Bekapor River Basin, the Mentiga River Basin, and the Bera River Basin. However, this studies comprehensively only focus on the Pahang River Basin (Fig.1.4). The Pahang River start at the confluence of the Jelai River and the Tembeling River and continues southward, then in an easterly direction through a series of river morphology and finally discharges into the South China Sea (Tekolla, 2010).

The basin area has a humid tropical climate that is affected by two monsoon periods: the northeast monsoon from November to March and the southwest monsoon from May to September. Normally, these two monsoons bring varies rainfall intensities depends on locations ranging from 1700mm to 3600mm annually (Malaysian Wetland Working Group, 1988; DOE, 2008). During the northeast monsoon, usually heavy rain was expected and has resulted in big flood along the downstream area (Abdul-Ghani, 2009). The transition period in between the monsoons is known as the inter-monsoon period. During this period, the basin normally experienced low amount of rainfall. On the other hand, the driest months in the basin are June and July (Tekolla, 2010; Khan et al. 1996; DID, 1974). Being located in close to the equatorial line and in tropical area, the average temperature throughout the year is high (> 26^{0}C).

In this study, twenty-one sampling sites were designed as sampling sites. The main locations of the sampling area are known as Ulu Tembeling (UT), Kuala Mai (KM), and Lubuk Paku (LP) which represent the upstream, middle stream, and downstream areas respectively. Moreover, all the sampling sites are located in the freshwater zone. In the upstream area, there are 8 sampling sites which most of the sampling sites conditions were in pristine or natural condition. However, there are also sites which were located close to a village, small scale agriculture and aquaculture activities. At the entrance to the national park, extensive human activity, including land clearing for the construction of hotels, resorts, and restaurants were observed. Cutting down of trees in the riparian zone has led to sediment erosion into the river. In addition, wastewater from the restaurants, hotels and houses have been directly released into the river without any proper

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It the middle stream area, there were six (6) sampling sites and most of the sampling sites were located in an agriculture and palm oil estate. By comparing the land use map produced in 2000, it was observed that the riparian vegetation covers along the river bank has dramatically decreased due to unsustainable land development and large scale of monotone agriculture i.e. palm oil plantation and rubber estate. Meanwhile for downstream area, there were seven (7) sampling sites in this area. The small-scale agriculture and aquaculture activities by land lord along the river bank were observed. However, it was observed that the riparian vegetation conditions in the downstream area are better than in the middle stream area because of the development of secondary forest. In addition, sand mining activity was observed at several places between middle and downstream area.

Fig.1.4 The location of Pahang state in the Peninsular Malaysia (references)

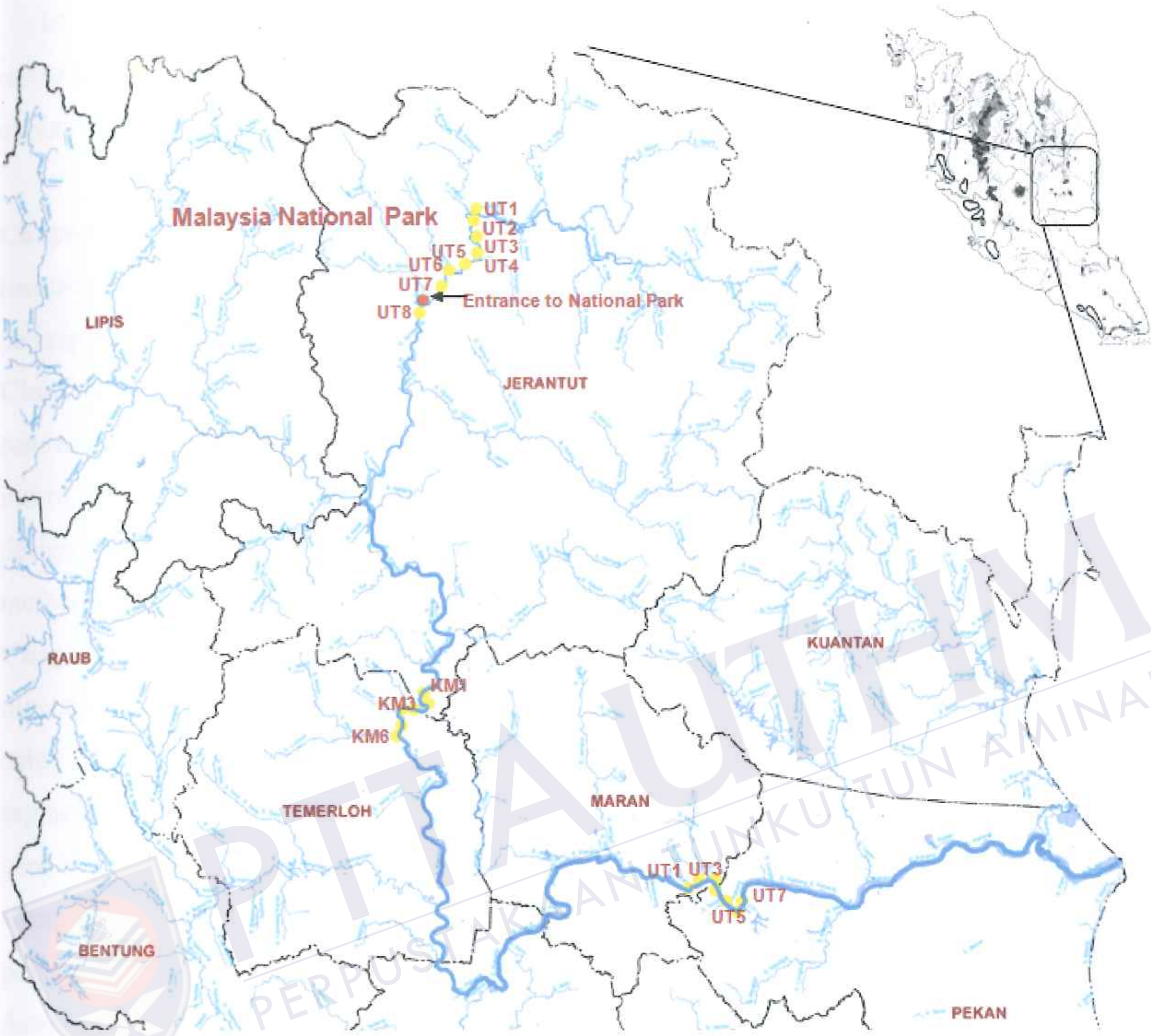

Fig. 1.5 The right figure shows a map of Peninsular Malaysia and the location of the Pahang River while the left figure shows the location of the three main survey sites: Ulu Tembeling, Kuala Mai, and Lubuk Paku

1.6 Dissertation Structure

In this dissertation, there are six chapters. Each chapter will explain a details result of research works which was carried out in this study. A brief introduction for each chapter is explained below:-

Chapter 1: This chapter is introductory chapter which will highlights the background of research, problems statement and research questions, research objectives, advantages of research, description of the study area, and dissertation structure.

Chapter 2: This chapter contains the main reference on the importance information such as the fundamental, theoretical background, and methods that being used in this study. All those information will be reviewed and analyzed in order to get clear and comprehensive idea to design the research flow. The literature review is based on the overview of existing assessment methods, statistical approaches, and the restoration and conservation approaches.

Chapter 3: This chapter will discuss about fish composition pattern in this river. Moreover, two diversity indexes were applied to calculate the species diversity and species richness. Later, by using statistical approaches known as TWINSPAN and MDS, the classification of river segments based on fish fauna was established. Further, this segment classification results will be used in the development of scoring criteria for IBI in chapter 4.

Chapter 4: This chapter will discuss about the assessment of environmental quality from the perspective of water quality and habitat quality. The water quality and habitat status were determined by calculate water quality index (WQI) proposed by DOE and modified habitat assessment proposed by Barbour et al. (1999) respectively. The assessment results of this chapter will be utilized as an input data to model the presence/ absence of selected fish species.

Chapter 5: This chapter will discuss about the development of Index of Biotic Integrity (IBI) for the evaluation of environmental quality. Fifteen IBI metrics were integrated to evaluate the river health based on fish fauna as biological indicator.

Chapter 6: This chapter will discuss about the application of modeling to model the presence/absence model of four fish species with regards to water quality and physical environment variables by using generalized linear model (GLM).

Chapter 7: This chapter offers the conclusion of the research works and also some recommendations for the improvement of current works.

Literature cited

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Chapter 2

Literature review on research methodologies

2.1 Relationship between environment and organisms

River topography and water flow regimes are complex and diverse. The changes in river environment throughout the river, including a decrease in number of river geomorphology such as pool and riffles caused by river improvement works and changes in river basin conditions have lead to changes in organic matter in river and thus affect population of fish, benthic animals and other organisms. Aquatic ecosystems perform many important environmental functions. For example, they recycle nutrient, purify water, attenuate floods, recharge groundwater water and provide habitats for wildlife (Loeb and Spacie, 1994). However, the health of an aquatic ecosystem is degraded when the ecosystems ability to absorb perturbation has been collapsed and this condition a result of physical, chemical or biological alteration of the environment. For instance, physical alterations include changes in water temperature, chemical alterations include changes in the loading rates of nutrients, toxins, while biological alteration include the introduction of exotic species and many more.

According to the statistic published by Malaysia's National Biodiversity Policy (1998), there is greater diversity of fauna in the country. Based on these data, there are about 300 species of will mammals, 700-750 species of birds, 350 species of reptiles, 165 species of amphibians and more than 300 species of freshwater fish. Freshwater habitats such as the lowland slow-flowing streams and upland rivers with water torrents support a diverse aquatic invertebrate fauna and variety of fish. A natural asset of Malaysia is, therefore, its wealth in biological diversity. Reduction in this biological diversity will distract the balance within ecosystem as it is generally accepted that a certain amount of species and genetic diversity is needed to uphold the relations within the ecosystems and hence maintain ecological services. Losing diversity means losing the ecosystem resilience, leading to adverse effects on human lives (Raja-Omar et al., 2004).

Regarding to river environmental pollution problems, it has a very long history. For instance, the rapid development of tin mining, a traditional industry such as rubber and palm oil that started at the turn of the century about 100 years ago has polluted the river in term of increasing of wastewater and sludge. From the late 1960's Malaysia pursued rapid industrialization supported by foreign investment that resulted in tremendous increased amount of industrial wastewater and other wastes and this problems obviously affected urban areas. Nowadays, as in many other developing countries, the state of rivers is appalling and in many urban areas, rivers have been literally turned into open sewers, some to the extent of being non-rehabilitate and we are paying it tolls (Chan et al., 2003)

2.2 What is River Health?

In the last two decade, the 'river health' or 'ecological health' terms are introduced and widely debated. Some researchers argue on using this term to evaluate the river condition. Suter (1993) insists that "river health" is an inappropriate metaphor because it is not an observable ecological property. He mentioned that ecosystem is not organisms, so they do not behave like organisms such as health. Also, health is not an operational concept for physicians or health risk assessors because they must predict, diagnose, and treat specific state called diseases or injuries; they do not calculate indexes of health. Some authors has offered an argument to counter Suter explanation by searched for more objective or scientific arguments for referring to health in ecological context, often equating health with properties such as "self-organizing", "resilient", and "productive". Thus, to make clear the meaning of health in the context of "river health", increased examination of relationships between environmental variables that affect aquatic biota, such as habitat structure, flow regime, energy sources, water quality and biotic interactions and biological condition are required in the study of river health (Karr et al. 1986)

Nowadays, the term of 'river health' is widely understood concept. The meaning of "health" is not more than just a plants and animals that live in a river or the quality of the water in it. It also depends on the diversity of the habitats, plant and animal species, the effectiveness of linkages and the maintenance of ecological processes (Karr and Chu, 2000). According to Schofield and Davies (1996) river health can be defined as; the ability of the aquatic ecosystem to support and maintain key ecological processes and a community of organism with a species composition, diversity, and functional organization as comparable as possible to that of undisturbed habitats with the region. River health is taken to mean the degree of similarity to an undisturbed river of the same ecoregion, particularly in terms of its biological diversity and ecological functioning (Karr and Chu, 1999).

The basic foundation of river health assessment involves comparisons. Basically, indicators that used to represent the river health are generally will be compare between two different sites; comparison between study sites with reference sites (Karr et al., 1986; Oberdorff and Hughes, 1992). Usually, the state of reference site is the site which closely resembles natural condition or less disturb site which could represent the condition of the region. A recent development in river assessment has been the use of reference conditions rather than reliance on single sites or average values for the whole river as controls. The function of these reference sites are to serve as the control against study site conditions which has been compared. These comparisons approach are proved to be useful and success to be applied in evaluating river health in Australia (Norris and Norris, 1995).

According to Karr (1981) and Karr and Chu (1999), reference site is a site with unimpaired condition, reflective of natural, pristine, reference or benchmark ecosystem. In Malaysia, relatively few rivers remain in undisturbed or pristine state except the stream or rivers located deep in the forest with no access road. Most of the rivers are affected by a number of in-stream activities, riparian degradation, catchment modifications or practices. This conditions usually resulted in lower ecological value and less biological function than their original states. The reasons why we need to measure the river health is because of the rivers value itself. Nowadays, river has been manipulated and used in many perspective ways to fulfilled and satisfied our need such as water resources, water supply, water for irrigation, navigation, fishing, and recreation. In another words, if we fail to protect the biology of our waters, we will not protect human uses of that water. When rivers can no longer support living thing, they will no longer support human affairs (Karr and Chu, 1999). Thus it is very important for us to measure the river health.

2.2.1 Changes approaches of river environment assessment

In the last two decade, the approach for the assessment of river health was well expanding and most of the assessment approaches has integrated the biotic factor in the assessment parameters. In the past, the physico-chemical parameters would react to changes in stream flow, land use and riparian condition and it is generally used in indicating stream and catchments health. Physical parameters included flow, temperature, conductivity, suspended solids, turbidity and color. Meanwhile, the chemical parameters included pH, alkalinity, hardness, salinity, biochemical oxygen demand, dissolved oxygen, total organic carbon and also nutrient such as phosphate and nitrate. However, the used of physical and chemical parameters cannot express the condition of biological conditions and several researchers has suggested the integration between conventional approach with biotic factor could provided a better insight regards to stream health. In Malaysia, until today there are no laws or act was established to evaluate the condition of our river health. Normally, the assessment of our river was solely based on physico-chemical assessment that was conducted according to the methods proposed by Department of Environment (DOE).

Bio-assessment is a method which directly measures the biotic characteristic of stream. According to Friedrich *et al.* (1992) alteration of stream habitat, hydrology or water quality could affect the aquatic organisms such as changes in species composition of aquatic communities, changes in the dominant groups of organisms, impoverishment of species, high mortality of sensitive life stages, mortality in the whole population, changes in behavior of the organisms, changes in physiological metabolism, and histological changes and morphological deformities. In addition, the bio-assessment method consists of a wide range of bio-indicators. It is impossible to sample all biotic parameters as it would need a huge sum of money time. As an alternative, target species are selected. Species that were easy to catch and identify might be the practical choice of indicator, but a meaningful assessment of stream health could only be obtained if the relationship between the ecosystem and the selected indicator could be identified. Hence, in assessing stream health, the most promising target species appeared to be found are benthic algae, macro invertebrates and fish.

Habitat is defined as ecological area that is inhabited by a particular species of animal, plant, or types of organism. Normally, good habitat consists of good physical and chemical condition that suitable to support the living thing (Townsend and Hildrew, 1994). According to Gordon *et al.* (2004), habitat quality could be expressed as the presence or absence of suitable habitat, the area available of ideal habitat or a rating of the relative quality of the habitat that is present. Generally, spatial and temporal habitat variability and biological diversity in rivers are closely related. The target of habitat assessment is generally to measure the in-stream and riparian conditions that influence the structure and function of aquatic community in a stream. One of the major stressors of aquatic system is the presence of an altered habitat structure. The stream health assessment techniques are designed for a diverse range of problems and environment. Some examples of the habitat-based stream health assessment are Rapid Bio-assessment Protocol (U.S. EPA), Habitat Evaluation Procedure (HEP), Habitat Suitability Index (HSI) and Hydrogeomorphic Index (HGM). By integrating all those mentions variables in assessing river health such as (WQI, biotic factors, and habitat quality), these could serves as new evaluation and assessment methods that could provide better result.

2.2.2 Diversity Index to measure the river health

A diversity index is a statistic which is intended to measure the local members and it can use in various field of study to assess the diversity of any population. The application of diversity approach can applied in the field of ecology to measure biodiversity in ecosystem, demography to measure the distribution of population of various demographic groups, information science to describe to describe the complexity of a set of information, and in economics to measure the distribution over sectors of economic activity in a region (Hughes & Noss, 1992).

Biological diversity can be quantified in many different ways. Two main factors that need to be taken into account when measuring diversity are richness and evenness. Richness can be as a measurement of the number of different kinds of organism that present in the particular area. In other word, species richness is the total number of different species present in a community. Some communities may be simple enough to allow complete species counts to determine species richness. However, this is often impossible, especially when dealing with insects and other invertebrates, in which case some form of samplings has to be used to estimate species richness. While evenness can be define as relative abundance of the different species which making up the richness of the studied area.

In Malaysia, the diversity concept was coupled with WQI to assess the stream health (UM-DOE, 1986). The basic concept of this assessment is by considered species richness and evenness as well as water quality assessment. Kasan (2006) had studied about the relationship between water quality and algae population in Pontian Kecil River and he suggested the Water Quality Index (WQI) and Shannon-Weiner Diversity Index (H') have a significant correlation. Gammon et al., (1981) used diversity indexes to evaluate fish communities in the Wabash River by combine number of individuals and biomass per km of stream with

Shannon-Weiner diversity index. Thus, is it proved that the combination between diversity index and WQI could reflect the condition of river health. Equation 2.1 shows the equation that can be used to calculate Shannon-Weiner Diversity Index (H'):

$$Shannon - Weiner\ Diversity\ Index\ (H') = \sum_{i=1}^{n_g} Pi \ln Pi \qquad \text{Eq. 2.1}$$

where n_g denotes the number of genera while Pi is the proportion of each species in the sample and ln is $\log_{10}$. According to Malaysian Water Quality Classification Classes, river condition can be classified into five classes: class I, class II, class III, class IV, and class V (Table 2.1).

Table 2.1 Water quality status and classes based on Shannon-Weiner Diversity Index (UM-DOE, 1986)

Diversity index (H')	Classes	Water quality status
>3.73	I	Very clean
2.80-3.73	II	Clean
1.86-2.80	III	Moderate polluted
0.93-1.86	IV	Slightly polluted
0.00-0.93	V	Severely polluted

2.2.3 Multi-metric approach (Index of Biotic Integrity, IBI)

In the last few decades, biologists have taken advance step by testing several approaches to provide a better biological assessment. Most of the approaches rely on indicator species to reflect low or high quality of the stream condition. One of such approach is Hilsenhoff's tolerance index (1977) which used benthic invertebrate to evaluate the environmental quality. However, this applicability of this index is limited because the tolerance of aquatic invertebrates to toxicant or pollutant have not been precisely defines in many areas, especially for species which is difficult to distinguish. The rational for the usage of biological assessment is that environmental perturbation leads to a reduction in the number of species and to dominance by a small number of tolerant species.

The accurate assessment of biological condition requires a method that integrates biotic response through an examination of patterns and processes from individual to ecosystem levels (Karr *et al.*, 1986). The indicator species concept has dominated biological evaluations

(Ganasan and Hughes, 1998; Karr et al, 1986). Omernik (1995) suggested the use of multi indicator species (to investigate or relate) at any single level of individual, ecosystem, components and stresses. Ecological studies typically focus on limited number of parameters that might include one or more of the followings; species distributions, abundance trends, standing crop and production estimate (Barbour *et al.*, 1999).

The strength of the multi-metric approach is its ability to integrate information from individual, population, community and ecosystem levels. By integrate several metrics; it can minimize the weaknesses that may have in single metric (Karr *et al.*, 1986). Current research is being conducted to test the efficacy of this application (multi-metric concept) to lakes, reservoirs, estuaries and large rivers (Karr & Dionne, 1991; Minns et al. 1994; Lyons et al. 1995). According to Barbour et al., (1999), the metric uses in evaluating the condition of river must be (i) relevant to the biological community, (ii) meet and achieved the objectives of study, (iii) can detect and sensitive to stressors, (iv) can distinguish the changes, and (v) cost effective.

In evaluating the conditions of river health by using a fish as indicator, most of the research has follow a methods and principle which was delineated or developed by Karr et al., (1986) in grouped the fish assemblage into three classes; (i) species richness and composition, (ii) trophic composition, and (iii) fish abundance and condition. Since the introduction of this concept, many research has test this concept to reveal the effectiveness of this method. Since then, it has been tested and found useful throughout in many regions of North America (Angermeier and Karr, 1994), Europe (Oberdoff & Hughes, 1992), Asia (Ganasan & Hughes 1998) and South America (Cassati & Ferreira 2009).

2.2.3.1 Fish as biological monitors

With regard to biological communities, the communities assemblages pattern reflect a combination of current and past watershed conditions because organism are sensitive to changes across of wide array of environmental factors (Karr et al., 1986). In evaluating the river health by using biological communities, most of the aquatic organism has been test as an indicator such as Fish (Fausch et al. 1990; Ganasan and Hughes, 1998), algae (Porter, 2008; Stevenson and Smol, 2003; Wan-Maznah, 2010), macroinvertebrate (Weigel et al.